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BIOLOGICAL BULLETIN

FORM-REGULATION IN CERIANTHUS, IX.

Regulation, Form, and Proportion.

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Regeneration and Proportion.

In the second paper of this series (Child, '03*b*) attention was called to the fact that the amount of regeneration is not proportional to the size of the piece. Small pieces above a certain limit regenerate as rapidly as pieces many times their size up to a late stage. Finally the small pieces fall slightly behind those of large sizes, probably as was suggested, because of the exhaustion of the material available for regeneration under the particular conditions (relative exhaustion, Child, '03*b*). Evidently the exhaustion will occur earlier, other conditions remaining the same, as the size of the piece decreases. Consequently there is some difference in the amount of regeneration according to the size of the piece, but this difference appears only at late stages and is very much less than the difference in size between the pieces. In other words the regenerated structures of small pieces are always relatively larger than those of large pieces.

The two series 54 and 55 which were described fully in my second paper (Child, '03*b*) illustrate this fact so well that it is desirable to recall certain points in this connection.

In the preparation of the two series the disc and œsophagus were removed by a transverse cut just aboral to the œsophagus and then the remaining portion of the body was cut into two pieces *A* and *B*. In Series 54*A* the oral piece was about four times as long as *B* at the time of section, while in series 55 the aboral piece *B* was about four times as long as *A*. Ten specimens were used for each series. In the pieces *A* of the two

series we have pieces ending orally at the same level of the body, but of very different lengths. For purposes of direct comparison as regards rapidity and amount of regeneration pieces must always end at the same level of the parent body for the rapidity and amount of regeneration differ markedly with the difference in level (Child, '03*b*).

Comparing 54*A* and 55*A* it was found that, although the former pieces were about four times as long as the latter, the regeneration at the oral end was the same in both during more than a month. Finally in the latest stages the shorter pieces fell slightly behind the others, but even then the difference in length of tentacles in the two sets was only 1–2 mm. Figs. 1 and 2[1] represent diagrammatic sections of 54*A* and 55*A*, thirty-one days after section, when regeneration was about completed — the experiment was performed during December and January, consequently the total amount of regeneration was much less than in the summer specimens. The length of the tentacles in the figures is the average length for the pieces of each set, but since there was little difference in individual pieces the figures would serve equally well to represent almost any of the pieces of the two sets.

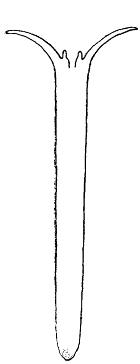


FIG. 1.

The marginal tentacles in the pieces 54*A* (Fig. 1) were 7–8 mm. in length, while those of 55*A* (Fig. 2) were 6–8 mm. in length, *i. e.*, in some of the shorter pieces the tentacles were slightly shorter than in the long pieces, probably in consequence of the relative exhaustion of these pieces (see Child, '03*b*). The labial tentacles show scarcely any perceptible difference; the average length of these in 54*A* is 1.25 mm. and in 55*A* 1 mm. or a little more, but as these vary more

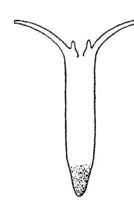


FIG. 2.

[1] All the figures of this paper are diagrammatic outlines drawn from measurements of the living specimens. The stippled region at the aboral end represents the aboral new tissue. It is represented as if the body were seen in surface view, not in section, in order to indicate the shading in color between new and old parts and the absence of a sharp distinction. The oral end of the body is represented in section but the œsophagus is not drawn in most cases since it was usually impossible to determine its length in regenerating specimens.

in a single piece than do the marginal tentacles the very slight difference is not important.

Aborally the amount of regeneration was much greater in the smaller pieces 54*A* than in the larger 55*A* in consequence of the difference in position or level of these ends with respect to the animal from which they were taken (Child, '03*b*). Considering the relative amount of regeneration in the two pieces we find that it is much greater in the smaller pieces. But the important point for present purposes is the absence of proportionality.

Another series, Series 46, affords similar results. In this series disc and œsophageal region were removed from twelve large specimens by a transverse cut just aboral to the œsophagus. Four of the pieces (Ser. 46*A*) were kept without further operation, four others were cut in half and the distal half used (Ser. 46*B*) and from the oral ends of the remaining four small cylindrical pieces about 5 mm. in length were cut (Ser. 46*C*). Thus three sets of pieces were obtained all with oral ends representing approximately the same level of the original specimens. The pieces *A* were about four fifths of the total length of the body, the pieces *B* about two fifths, and the pieces *C* about one fifteenth or less. During the earlier stages of regeneration there was no appreciable difference in the rate or amount of regeneration in the three sets except as regards two pieces of *C* which broke up into smaller pieces and did not regenerate at all, a common phenomenon in pieces near the lower limit of size. Five weeks later when regeneration was complete the marginal tentacles of the pieces *A* were 7–8 mm. in length, those of *B* 6 mm. and those of *C* 4–5 mm. The differences in the labial tentacles were similar. While the length of the tentacles in the smaller pieces is not as great absolutely as in the larger it is relatively much greater. The pieces *C* were only about one twelfth the length of the pieces *A* but they regenerated tentacles more than half as long. Moreover, if we compare these pieces with the entire animals in which the marginal tentacles vary in length from 25–35 mm. we find that pieces one fifteenth of the size of an entire animal and taken from a region some distance from the oral end, *i. e.*, from a region where the power of regeneration is less than at the oral end, regenerate tentacles one seventh of the maximum

length. However much the small pieces may elongate and decrease in transverse diameter the tentacles remain "too large."

Various other series of my experiments afford similar results, but these two cases are sufficient as illustrations.

Stated in general terms the conclusions drawn from the experiments are as follows: as the size of the piece decreases the relative amount of regeneration increases — provided of course that the level at which regeneration occurs is the same in all cases. It follows from this that the form, *i. e.*, the proportions, of regenerated specimens may differ widely from the typical form and that either reduction of the regenerated parts or extensive new growth in the longitudinal direction must occur. Reduction of the tentacles occurs, as has been noted (Child, '04*e*) but it is due to change in external rather than internal conditions. If the pieces are fed they will of course in time attain approximately the typical proportions. But the important point is that the regenerative processes in absence of food are not proportional.

I am inclined to believe that these facts indicate that the stimulus to regeneration is as great in small as in large pieces; that the difference in absolute amount of regeneration is due to the earlier relative exhaustion of the smaller pieces, *i. e.*, the absence of energy available in the presence of a given stimulus; and that finally if this material could be supplied in such manner as to be available only for the regeneration of a particular set of structures, *e. g.*, the tentacles, they would continue to grow until equilibrium resulted between formative stimuli and destructive factors, no matter what the size of the piece, provided it was above the minimum. In other words, it is probable that the decrease in the absolute amount of regeneration in *Cerianthus* with decrease in size of the piece is due merely to decrease in amount of available energy and not to any inherent capacity for proportional regeneration. Furthermore, it is probable that various other cases of so-called proportional regeneration are in reality similar in nature to this case.

Regulative Changes of Proportion in the Old Parts.

The next subject which requires consideration is the change of form of pieces as a whole. A cylindrical piece cut from the body is of course relatively shorter and less slender than the

typical animal. From this piece tentacles regenerate at one end and more or less growth of new tissue occurs at the other, but neither of these is proportional to the size of the piece. It has already been shown that the oral regeneration is too great in amount to permit the reduction of the piece to the typical proportions, but there remains the further question as to whether the piece shows any approximation to typical proportion, or in other words whether changes in proportion of the old parts of the piece occur which can be interpreted as constituting an approach to the typical form.

In order to answer this question careful measurements of the pieces repeated at frequent intervals are necessary, but measurement is a difficult and uncertain matter in connection with *Cerianthus.* The form varies so greatly with different degrees of distension and with the different activities of the animal that it is impossible to obtain anything more than a rough approximation. I have, however, carried out several series of measurements extending over two months or more and have succeeded, I think, in minimizing some of the sources of error. In making these measurements various precautions were observed; the pieces were absolutely undisturbed for several hours, or in most cases for nearly a day before the measurements were made, since it is only in this way that anything like complete distension and elongation can be obtained. Measurement was made by immersing a small millimeter measure in the water with the specimen, care being taken not to touch it, for a touch is likely to cause instant contraction. All measurements were repeated several times at intervals during the day, for there is no certainty that the animal is fully distended at the time of a given measurement. From these different measurements the maximum series was selected as showing the largest size attained by the specimen during a given day. The following dimensions were measured for each piece so far as the parts designated were present; the whole length of the piece from disc to aboral pore; the length of the marginal tentacles; the length of the labial tentacles; the length of the aboral outgrowth of new tissue; if such were present; the diameter of the disc, *i. e.*, the distance between bases of tentacles on opposite sides; the diameter about half way between the disc and the middle of the piece, designated as oral diameter;

the diameter at the middle in some cases where it differed from the oral diameter; and finally the diameter about half way between the aboral end and the middle, designated as aboral diameter. At the same time diagrams were drawn showing any pecularities or special features of the regeneration which might occur. All the figures of this section were drawn from these measurements and diagrams. In cases where the tentacles differed markedly in length on different parts of the circumference the two tentacles of the figure represent the extremes.

No one can be more fully aware than myself that these measurements are not and cannot be more than rough approximations. Direct measurement of the labial tentacles was often impossible, but an estimate of their length was made in such cases by placing the measure as near to them as possible and making careful comparison. It is probable, on the other hand, that these measurements are as exact as the instability of form in *Cerianthus* will permit us to obtain. While I do not believe that extended investigation along this line is profitable in this case in consequence of the absence of stable form I have proceeded far enough to convince myself that such measurements are unable in a general way. Marked differences can certainly be detected.

The results obtained from the several series of measurements made agree in general though they showed some differences in detail, and I think it is possible to draw certain conclusions from them. The following series is selected as an example from among those made.

Series 36.

On October 20, 1902, disc and tentacles were removed from a large specimen by a transverse cut, and the body was then cut into four pieces, *A*, *B*, *C*, *D* (Fig. 3). These pieces were measured at intervals of two or three days during about six weeks.

The following table is an abstract of the measurements. The proportions of the whole animal before section, the estimated lengths of the pieces cut and the dimensions of these pieces on five different dates during the six weeks are given in millimeters. These are sufficient to show the general trend of the changes and measurements made in the intervals between these dates have therefore been omitted as unnecessary for the present purpose.

Date.	Piece.	Length of Body.	Length of Marginal Tentacles.	Length of Labial Tentacles.	Length of Aboral New Tissue.	Diameter of Disc.	Oral Diameter of Body.	Middle Diameter of Body.	Aboral Diameter of Body.	Figure.
Oct. 20, '02. Before Section.	Whole.	95	30	12–15		12	7	6	5	Fig. 3
Oct. 20, '02. At time of Section.	*A*	25								Fig. 3
	B	28								" 3
	C	12								" 3
	D	25								" 3
Oct. 21, '02.	*A*	9					5		6	Fig. 4
	B	15					6		6	" 9
	C	5					5		5	" 14
	D	10					5		3	" 19
Oct. 29, '02.	*A*	15	1–1.5				6	7	6	Fig. 5
	B	20					5	6	6	" 10
	C	6					4		4	" 15
	D	22					4	6	4	" 20
Nov. 6, '02.	*A*	10–12	7–8	0.5–1	1	6.5–7	6		6	Fig. 6
	B	18	4–5	0.5		6	5		5	" 11
	C	8–9	0.5–2			5	5		4.5	" 16
	D	18	0.5			4.5	4.5		4	" 21
Nov. 20, '02.	*A*	18	8–10	2–3	3	6	5		3.5	Fig. 7
	B	27	10–12	3–4	3	6.5	4		4	" 12
	C	10	5–8	1	2	5	4		4	" 17
	D	25	8–10	2		5	4		3	" 22
Dec. 2, '02.	*A*	27	12	3–4	3–4	6–7	4.5		3.5	Fig. 8
	B	28–30	12–14	3	3	6	4.5		4	" 13
	C	18	8–9	2–3	2	5	3		2.5	" 18
	D	25	11–12	3		5	3.5		3	" 23

A horizontal reading of the table gives the measurements for each piece at each date and the last vertical column headed "figure" gives the number of the text figure representing the piece at the stage indicated by the horizontal division.

It is readily seen from the table and figures that the length of each piece gradually increases while its transverse diameter gradually decreases during the course of the experiment. The length of the tentacles increases during the whole period. There are several irregularities in the table which are undoubtedly due to the great changes in form in individual specimens: for example, piece *A* is shorter on November 6 than on October 29. This difference is merely temporary and due to the fact that the piece is not as fully extended at the second measurement as at the first. But the general result is sufficiently clear from both table and figures. The extremely small size of the specimens on the day

after section is of course due to complete collapse. The pieces in this condition are not strictly comparable to the distended pieces.

The data indicate that a marked change in form occurs in these pieces and that this change consists in an approach to the typical proportions, although none of the pieces attain them. For example the piece *B* (Fig. 13) approaches most closely at

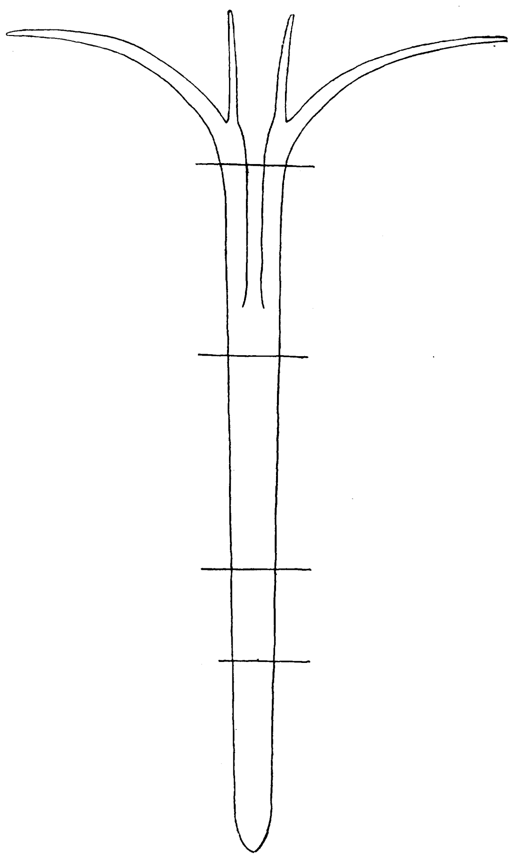
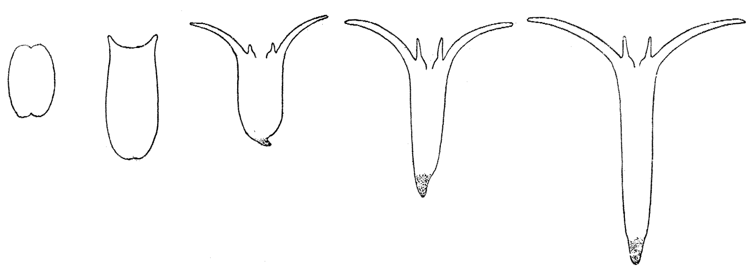


FIG. 3.

the end of the experiment to the original proportions of the whole before section, but even here the tentacles are relatively longer, the body-length is relatively less or the transverse diameter is relatively greater than in the whole. In the short piece *C* (Fig. 18) the proportion between length and transverse diameter is 6:1

as compared with about 13.5 : 1 in the whole. The relation between length of marginal tentacles and length of body is about 1 : 2 while in the whole it is 1 : 3. The change in the relation between length and transverse diameter in each piece during the experiment consists chiefly in decrease in the latter. None of the pieces except *C* have increased in length to an amount equal to the growth of new tissue at the aboral end. In other words all but *C* both length and transverse diameter of the old tissue have decreased but the latter much more rapidly than the former. In the actual decrease in size two factors are probably concerned, viz., loss of substance and decrease in general internal pressure : of these the former is due to starvation and use of material in

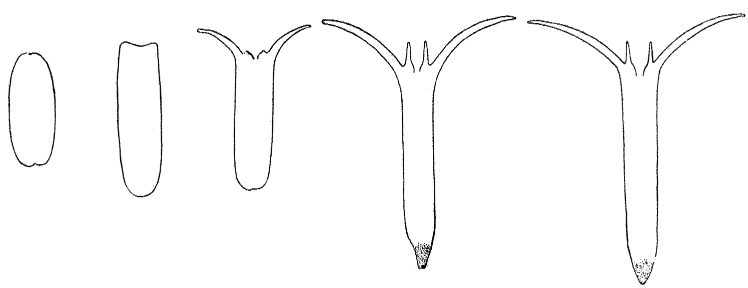


4 5 6 7 8

regeneration, the latter both to approaching exhaustion and to the reduction in temperature which occurred during the course of the experiment from October to December ; both of these conditions reduce ciliary activity and therefore internal pressure also. But these factors alone must bring about a proportionate or nearly proportionate reduction in form. Other factors must therefore be concerned in the change of form which occurs in these pieces.

It remains then to determine whether or not this change of form is due to some inherent capacity of the protoplasm independent of external conditions. The first point of importance in the consideration of this question is the dependence of the change of form upon distention with water. Pieces kept open at one or both ends continue indefinitely to grow shorter and smaller until finally they form rounded masses, even though originally the length was many times the diameter ; in short the changes in these collapsed pieces are opposite in character to those that occur in

the pieces described above. The reduction of collapsed pieces has been mentioned several times in this series of papers (see especially '04*b*) and need not be discussed in detail again. The fact that the relation between length and transverse diameter changes in opposite directions in collapsed and distended pieces is important and may, I think, be taken to indicate that the distention with water plays some part, either directly or indirectly, in the "elongation" which distended pieces undergo. Two possibilities suggest themselves to me in this connection, viz.: either the pressure of the water in the enteron constitutes in some way a stimulus to elongation or the change of form is an



9 10 11 12 13

incidental result of the behavior which is markedly different in distended and collapsed pieces.

Regarding the first of these possibilities, viz., internal pressure as a stimulus to elongation I can offer no experimental evidence. I desire merely to call attention to certain points. It is evident that the general internal pressure cannot constitute a stimulus to elongation unless we postulate a difference in the reactive capacity of the tissues in different directions; it may be that such a difference exists but I know of no basis of fact for this assumption. On the other hand it is possible that currents in the enteron might exert local pressure in particular directions. It has already been noted in numerous cases (Child, '04*b*, '04*c*, '04*d*, '04*e*, '05) that there is some ground for the belief that circulatory currents (Child, '04*b*) may constitute factors in the localization of regeneration, *i. e.*, that the local pressure may act as a stimulus to growth. Currents passing orally along the inner surface of the body wall in all the intermesenterial chambers must produce a

total pressure of considerable amount upon the oral end. On the other hand a current passing aborally along the inner margins of the mesenteries or a part of them must finally strike the aboral end and produce pressure there. Now the effect of these currents may conceivably show itself partly in local growth in region of impact, *i. e.*, where the tension upon the tissues resulting from the impact of the current is greatest and partly in a diffuse growth or a change of form in accordance with the tension in the surrounding regions to which some degree of the tension is transmitted. Since these currents strike the terminal regions of the body local growth at the ends and elongation of the whole must be the result if they are effective in the manner suggested. In pieces kept without food the elongation must be accompained

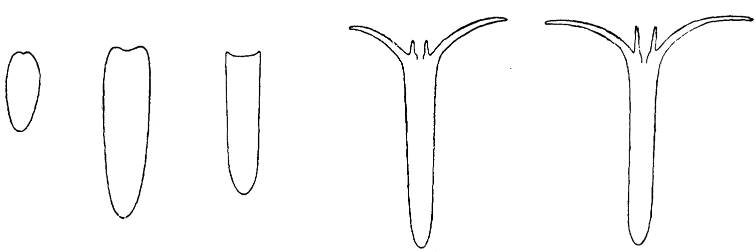
14 15 16 17 18

by a reduction in the transverse diameter. These suggestions as to the effects of circulatory currents, like those made in previous papers (Child, '04*b*, *et seq.*) must be regarded at present as merely tentative. They may be entirely incorrect but I think the hypothesis of the effectiveness of circulatory currents as localizing formative stimuli cannot be rejected off-hand. It serves so well as a basis for explanation of various phenomena that it must at least receive consideration. I hope at some future time to obtain experimental evidence regarding this hypothesis.

The second possibility, viz., that the change of form may be an incidental result of the movements of the animal must also be considered. As noted above, the behavior of typically distended specimens is very different from that of the same pieces during collapse. The creeping habit of *Cerianthus* is well known; the animals are able to move about freely, lying upon the side and moving with either oral or aboral end in advance. They move not only on horizontal surfaces, but are able to climb the vertical sides of a glass jar or aquarium. In my aquaria specimens often

climbed two feet or more up the vertical side. Cilia afford of course the motive power and the slime secreted serves as a means of adhesion to surfaces. Observation of creeping pieces shows clearly that the body is subjected to more or less tension in the longitudinal direction during this movement. Probably the slime secreted by the ectoderm is responsible for most of this tension. I think it possible that this tension may bring about some degree of elongation in much the same way as in *Stenostoma* (Child, '02, '03).

In *Cerianthus* the tension is due rather to the slime secreted than to the use of the end as an organ of attachment, as is the case in *Stenostoma*, but the result, viz., longitudinal tension upon the tissues, is similar in both cases. If the tissues here are af-



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fected by the tension as they are in the turbellaria, elongation must result, whether from growth or from mechanical rearrangement of the tissues or cell-elements.

Soon after beginning my experiments I found that collapsed specimens and pieces in early stages of regeneration crept about very little. It was found that such pieces could be kept without danger of loss in Stender dishes with sides 7–8 cm. in height, which were placed on the bottom of large tanks filled with water; the pieces never crept out. Later, however, the same pieces would creep out of battery jars with sides 30–40 cm. or more in height. In these respects I noted a difference between those pieces which still retained the original oral end and tentacles and those in which oral structures were in process of regeneration. Pieces of the first sort began to creep about soon after closure of the aboral end and distension occurred, *i. e.*, within a few days in many cases, while the pieces with regenerating oral ends usually

moved very little during the first three to four weeks after section, *i. e.*, before regeneration of the oral structures was well advanced. In short, the collapsed specimen and the specimen — collapsed or not — in which the oral structures are not well developed, do not exhibit the typical behavior of the species as regards movement. Probably in the one case the absence of distension brings about some change in the internal stimuli which inhibits the motor impulses to a greater or less extent. In the other case the most highly organized portion of the body — the oral region — is absent and the reactions of the pieces are much less vigorous and effective.

To sum up: two possible factors in the elongation of pieces have been suggested; the one, tension upon the terminal regions of the body in consequence of the impact of enteric circulatory currents against the wall; the other, tension upon the tissues in the longitudinal direction in consequence of movement over surfaces accompanied by some degree of adhesion.

It is impossible to determine at present whether one or the other of these factors is chiefly concerned, or whether both play important parts in the change of form. It may be that other unknown factors are concerned, but it is highly improbable that there is any mysterious internal ultra-physico-chemical factor which brings about a characteristic form. Mention has already been made of the fact that collapsed pieces never undergo this change of form, but depart farther and farther from the "typical" form. Now it is possible to keep a specimen collapsed by means of a very small opening at one end or elsewhere, provided this be reopened frequently. It is difficult to understand how such an opening should interfere with any internal or "vitalistic" factor capable of causing return to the typical form. Here again experiment indicates the impossibility of explaining the facts with the aid of Driesch's hypothesis (Driesch, '01, '03).

Both of the hypotheses suggested belong in one category, viz., that of mechanical tension. Whether this tension brings about simply mechanical deformation of the tissue elements, or whether it acts as a functional stimulus to which the tissues react by growth, cannot readily be determined. Probably both mechanical deformation and growth occur; indeed, it is probable that the former brings about the latter.

According to this view the elongation of pieces of *Cerianthus* and the extremely elengated form of the body of normal animals are due to the same factors.

The tubicolous habit of the animal may perhaps be regarded by some as responsible in some degree for its elongated form. In the tube only longitudinal increase in size can occur. The animal frequently leaves its tube, however, and burrows in another spot; the size of the new tube will be determined by the size of the animal in each case. Moreover, I do not think the reduction in transverse diameter observed in pieces can be explained in this manner. The slime which encloses the bodies of specimens kept in clear water is not sufficiently elastic to reduce the diameter. In so far as the burrowing tubicolous habit is correlated with the creeping habit, it may constitute a factor in the production of the characteristic elongated form.

One point still requires brief consideration. The table and the figures indicate that piece *C* undergoes a much greater change of form than the other pieces. It is the only piece in which the length of the old part is greater at the end of the experiment than at the beginning, *i. e.*, provided the measurements are correct. There is of course uncertainty regarding all the measurements but if we suppose this difference between *C* and the other pieces to be real it requires explanation.

In my study of *Stenostoma* (Child, '02, '03) it was shown that the change in direction of the tension upon the tissues is an important factor in change of form. In a short piece of *Stenostoma* using its posterior end as an organ of attachment the directions of the various strains to which the tissues are subjected differs much more from those to which they were subjected as a part of the whole than would be the case in a long piece. This must be true in all cases except where the posterior end of the piece formed the posterior end of the whole. In that case the directions of the strains remain as before. For further consideration of the case the reader is referred to the above-mentioned paper. The point of importance for our present purpose is that the short piece must undergo greater change of form than the large piece except when it is taken from the posterior end.

We can I think, apply the same course of reasoning to *Ceri-*

anthus. If we consider animals moving about, oral end in advance as they very commonly do, a cylindrical portion of the body situated at any region except the extreme end, is, let us assume, subjected to a certain degree of tension in consequence of the movement. Now since this piece is attached to other parts both at its oral and aboral ends about its whole circumference the strains to which its tissues are subjected are almost wholly parallel to the longitudinal axis. If now the piece be removed from the whole and allowed to regenerate in the typical manner closure of the ends and outgrowth of new tissue at the aboral end occur before the piece begins to move about. If now the piece begins to creep and is in consequence subjected to tension the elements of this tension affecting various parts will differ not only in amount but also in direction because the piece is no longer attached to other parts at both ends by its whole circumference. Comparing a long and a short piece it is clear that the change in direction of the strains in the long piece considered as a whole is very much less than in the short piece. We may expect, therefore a greater change of form in the short piece than in the long piece, after equilibrium is attained. The greater change in the piece *C* as compared with *A*, *B*, and *D*, which I am inclined from comparison with other pieces to regard as real, may then be explained on the same basis as similar changes in other creeping forms. The fact, shown by the figures and table, viz., that the change of form became much more rapid toward the end of the experiment, *i. e.*, in the fifth and sixth weeks, agrees well with the fact that the piece did not begin to move about freely during the first month after section. During this time it never climbed out of the jar, but during the next two weeks it climbed out of a deep jar into the large tank almost daily and wandered about the tank. As often as found outside it was returned to the jar. It was during this time that the chief change of form occurred (compare Figs. 17 and 18). These facts may perhaps indicate that the movements are more important than the internal pressure in bringing about the change of form.

In *Cerianthus* then we find another case in which the assumption of a mysterious formative principle is in no way necessary. Form in the lower animals is probably to be considered as rela-

tively simple. It should be borne in mind, however, that cells and tissues of a certain constitution, *i. e.*, *Cerianthus*-protoplasm, must be acted upon in order that a certain result characteristic of the species may be obtained. In another species the result of a stimulus similar in degree and kind may be more or less widely different. At best the problem of form is complex but I believe that in general we must look to function for an explanation of form, whether direct or indirect, and not to form for an explanation of function. This opinion does not involve the paradox of differentiation of function in a structurally isotropic protoplasm, but requires a distinction between chemical and physical structure of protoplasm and morphological structure in general. Function in a general sense is an expression and result of the first, while the second is, at least in many cases, an expression and result of function.

Experimental Duplication of Parts.

By partial longitudinal splitting of the body, the separated portions remaining attached to the undivided part, it was possible to produce specimens with two oral or aboral ends as the case might be. In cases where one of the parts separated by the longitudinal cut was considerably smaller than the other, and especially in cases where the cut was somewhat oblique, the smaller part or that attached to the undivided region by the narrower portion very commonly separated from the remainder of the body within a few days and regenerated independently. In many cases also closure was much delayed by the irregular inrolling of the edges and one or both of the split portions became greatly reduced or constricted off. In a certain number of the pieces, however, the split portions roll longitudinally and their edges unite thus giving rise to the duplication. In case of duplication of the oral end the two parts are in reality "halves," each possessing approximately half the full number of tentacles. Where closure is perfect or nearly so each disc of course possesses a mouth and œsophagus formed by union of the longitudinal cut surfaces of the half œsophagus—in reality half structure. Whether in cases where one of these half structures contains the old siphonoglyphe the other ever forms a new one I do not know. I have never found a new one, but it may appear in time.

In cases of aboral duplication each part is really a "half," but the aboral pore is duplicated, each pore being formed from a part of the old pore in case the cut passed through it, or one pore being formed anew in case the cut passed more or less to one side of the old pore.

The varieties in method of closure in these cases are almost infinite as may be conceived from the discussion of inrolling in a previous paper (Child, '04*a*). Scarcely any two of the resulting forms are alike but the many differences in detail do not add essentially to our knowledge, being merely illustrations of one general principle. They do show very clearly, however, how little power the animal possesses to maintain or return to a particular form after section. All is pure chance in the matter of closure. Whatever portions of the cut surfaces come into contact unite. The tensions due to internal water-pressure may serve in some cases to modify the peculiar forms, but in other cases this does not occur. All depends upon the conditions of the particular case.

In cases where closure and duplication of the oral or aboral ends is accomplished I have never seen reduction, absorption, or loss by constriction of one of the two parts afterward. Occasionally if the duplication involves merely the extreme end it gradually disappears; the two halves gradually becoming a whole. In other cases where the duplication extends for some distance from the end so that the two parts are distinct, I have not noted any changes which might be interpreted as a regulation of the atypical form, although specimens of this kind have been kept for more than three months.

There is, no doubt, that many other varieties of monstrous forms may be produced. The only obstacle is the frequent separation of parts from the body after severe operation.

Summary.

1. Regeneration in *Cerianthus* is not proportional to the size of the piece. The smaller the piece, other conditions remaining the same, the greater the relative amount of regeneration. As regards absolute amount of regeneration the small and large pieces are at first alike, but later the small piece falls behind, *i. e.*, regeneration is retarded and ceases sooner than in the large piece, probably owing to lack of available energy.

2. Cylindrical pieces usually undergo a greater or less change of form during or after regeneration: this consists of an increase in length and a decrease in transverse diameter.

3. The change is slight during the earlier stages of regeneration before the oral structures are developed. It seems probable that it is the result, either directly mechanical or reactive or both of longitudinal tension upon the tissues. The tension in turn may be due in part to internal circulatory currents and in part to the habit of creeping over surfaces in the direction of the longitudinal axis.

4. In pieces maintained in the collapsed condition the change of form is the reverse, *i. e.*, the length decreases and the transverse diameter increases, at least relatively.

5. It is possible to produce forms with duplicated oral or aboral ends by partial longitudinal splitting: In cases of oral duplication each disc is essentially a "half" structure or fractional structure, bearing approximately the number of tentacles corresponding to the portion of the circumference which it represents. At the aboral end a new aboral pore may be formed in case the cut does not pass through the old pore.

6. No marked regulation, reduction or absorption of these duplicated structures has been observed except occasionally in cases where the duplication included only the extreme terminal portions.

7. The results of attempts to produce duplications and abnormal forms depend largely upon chance. Whatever portions of the cut surfaces come into contact unite and many peculiar forms result which may be more or less modified in some cases by the tensions and pressures to which the tissues are subjected.

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BIBLIOGRAPHY.

Child, C. M.

'02 Studies on Regulation, I. Fission and Regulation in Stenostoma. Arch. f. Entwickelungsmech., Bd. XV., H. 2 and 3, 1902.

'03 Studies on Form-Regulation, II. Experimental Control of Form-Regulation in Zoöids and Pieces of Stenostoma. Arch. f. Entwickelungsmech., Bd. XV., H. 4, 1903.

'03a Form-Regulation in Cerianthus, I. The Typical Course of Regeneration. Biol. Bull., Vol. V., No. 5, 1903.

'03b Form-Regulation in Cerianthus, II. The Effect of Position, Size, and Other Factors upon Regeneration. Biol. Bull., Vol. V., No. 6, Vol. VI., No. 1, 1903.

'04a Form-Regulation in Cerianthus, III. The Initiation of Regeneration. Biol. Bull., Vol. VI., No. 2, 1904.

'04b Form-Regulation in Cerianthus, IV. The Rôle of Water-Pressure in Regeneration. Biol. Bull., Vol. VI., No. 6, 1904.

'04c Form-Regulation in Cerianthus, V. The Rôle of Water-Pressure in Regeneration: Further Experiments. Biol. Bull., Vol. VII., No. 3, 1904.

'04d Form-Regulation in Cerianthus, VI. Certain Special Cases of Regulation in Relation to Internal Pressure. Biol. Bull., Vol. VII., No. 4, 1904.

'04e Form-Regulation in Cerianthus, VII. Tentacle-Reduction and Other Experiments. Biol. Bull., Vol. VII., No. 6, 1904.

'05 Form-Regulation in Cerianthus, VIII. Supplementary Partial Discs and Heteromorphic Tentacles. Biol. Bull., Vol. VIII., No. 1, 1905.